# Sensor Data Fusion For Hazard Mapping And Piloting

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# SENSOR DATA FUSION FOR HAZARD AVOIDANCE

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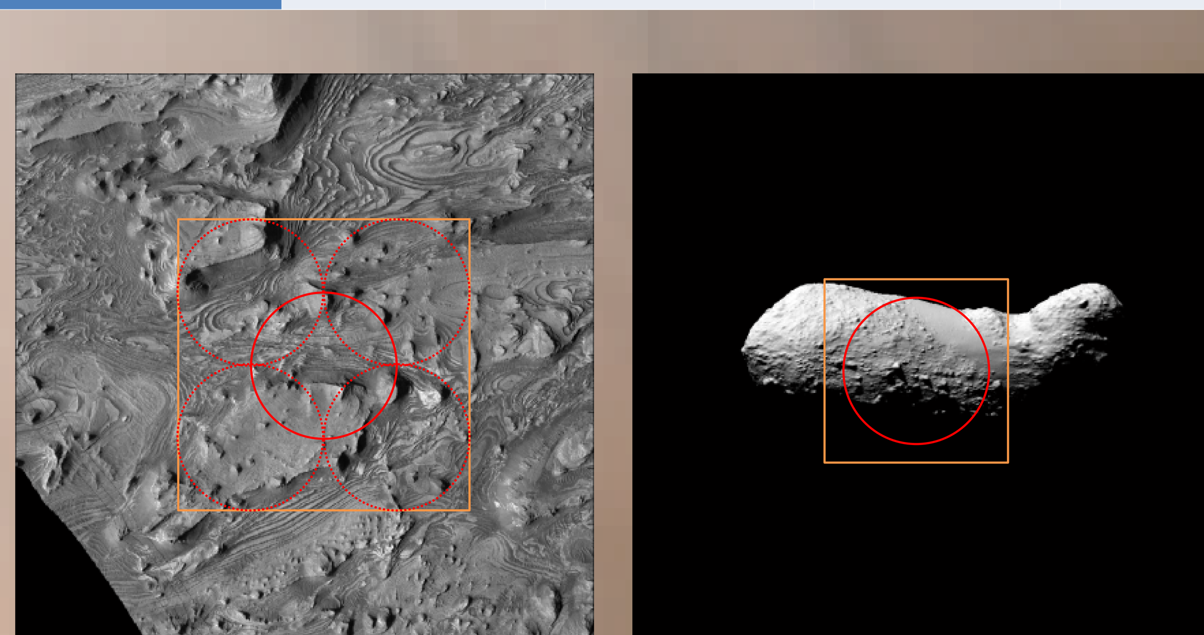
Autonomous landing on Mars, Moon or asteroids may require an autonomous Hazard Detection and Avoidance (HDA) system. Past studies on HDA or actual missions (such as Chang'E 3) dealt with the use of camera or LiDARs separately to detect dangerous slopes, boulders and shadowed areas. The present work, performed in the frame of an ESA Technology Research Program, proposes to use jointly a camera and a LiDAR to take advantage of each while mitigating their drawbacks, consequently improving the HDA performances. Various algorithmic solutions and sensor configurations are proposed and tested in the Mars and asteroid landing cases.

## Sensor configuration

The selected LiDAR is a last-generation TOF camera built by CSEM, using a laser source modulated in amplitude. The chosen camera is based on heritage from ESA and NASA studies.

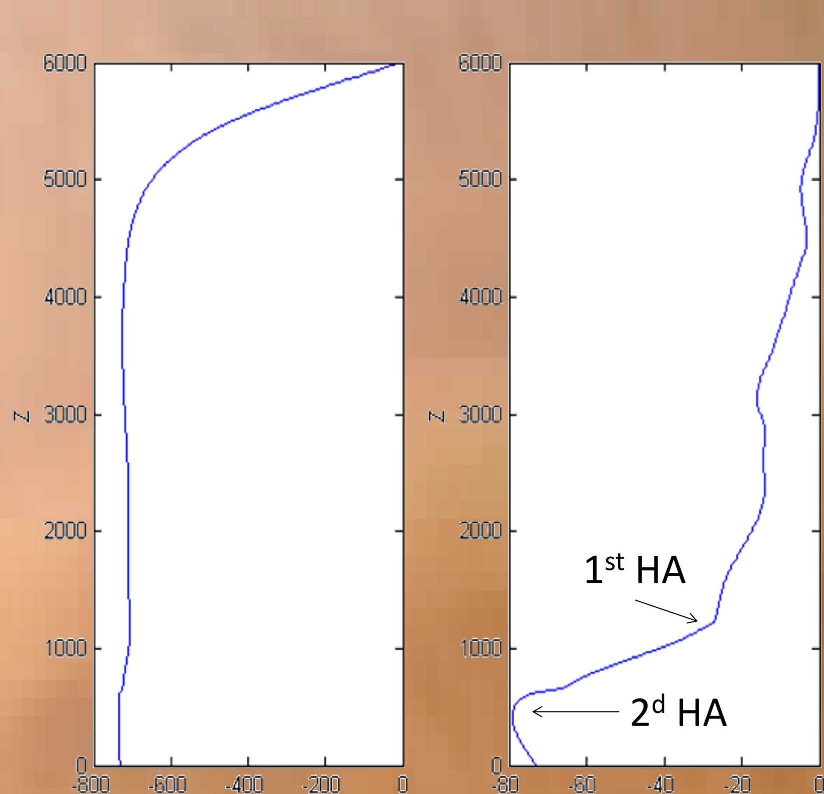
| | Mars | | Asteroid | |
|---|---|---|---|---|
| | Camera | LiDAR | Camera | LiDAR |
| FoV (°) | 70 | 38.8 | 25 | 8° |
| Array size | 2048x2048 | 512x512 | 2048x2048 | 512x512 |
| Fps (Hz) | 10 | 10 | 0.01 | 5 |
| Laser Power (W) | NA | 20 | NA | 20 |
| Number of lasers | NA | 5 | NA | 1 |



*Simulated camera image and LIDAR FoV (orange: receiver, red: laser)*

## GNC simulator

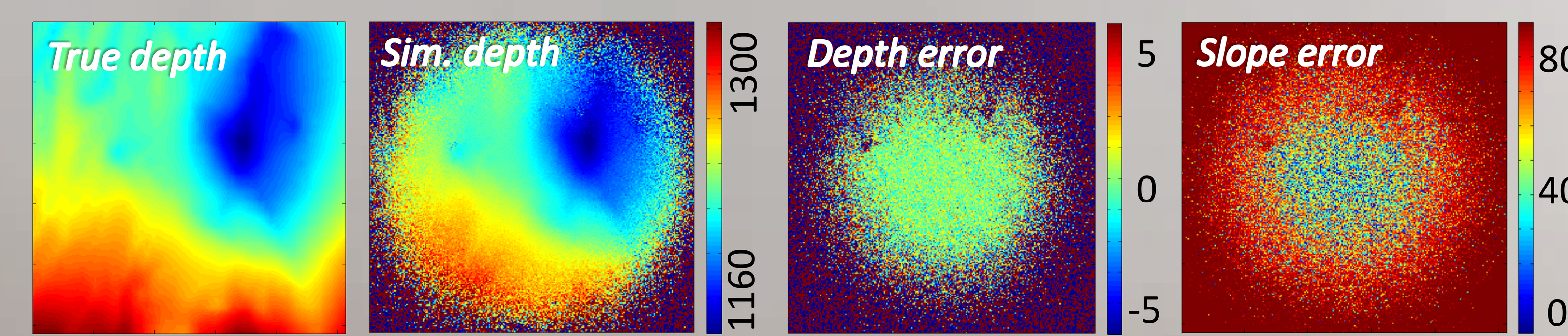
The HDA system is assessed within a complete GNC simulator, with image simulation and processing (point tracking and LiDAR altimetry) in the loop. It includes realistic sensor data simulation, and considers real Mars and asteroid terrains, extracted from NASA's PDS database.




*Mars landing trajectory*

**GNC performances at touchdown:**

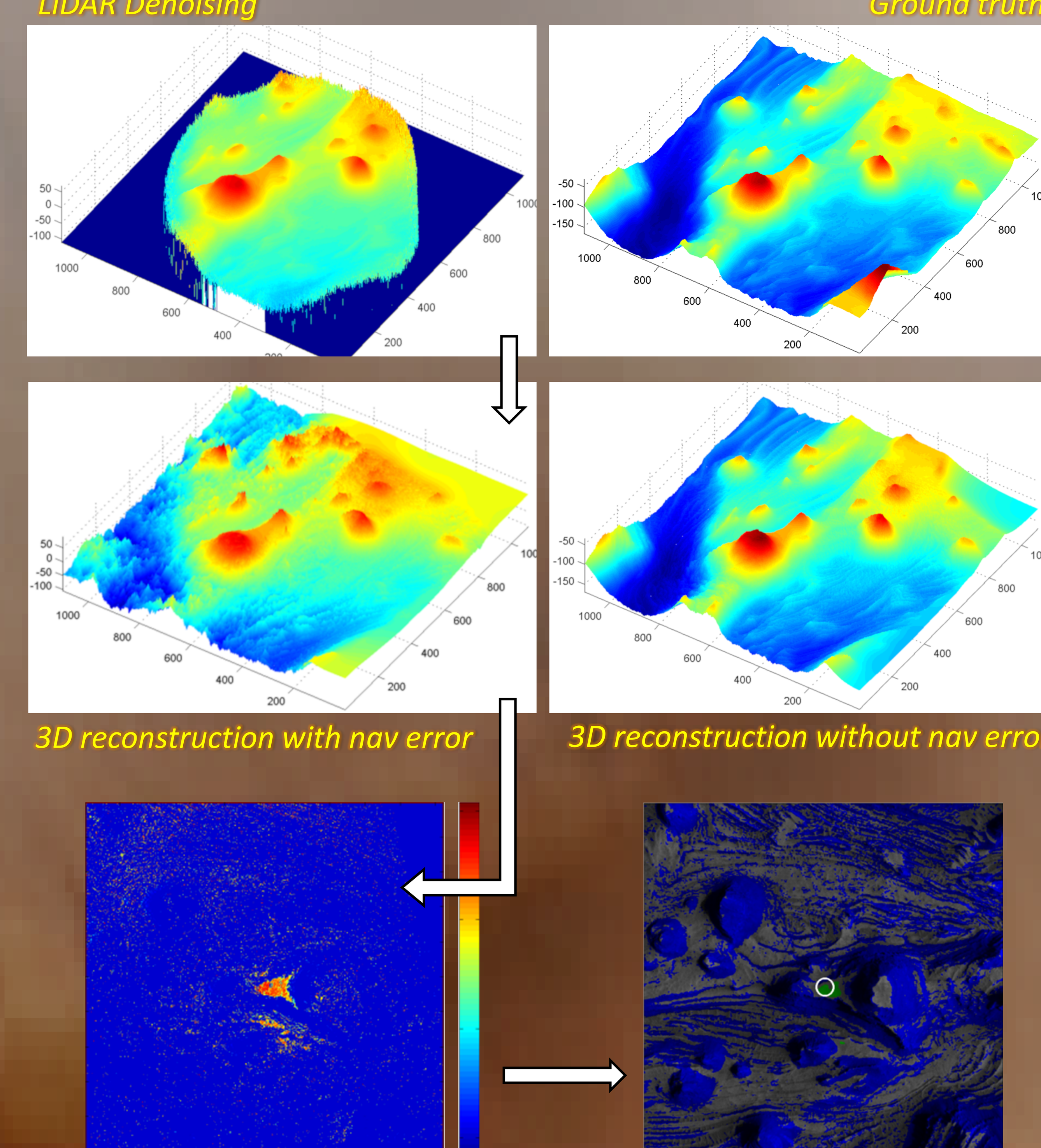
- Vertical velocity < 0.6m/s
- Horizontal velocity < 0.4m/s
- Attitude rate < 10mdeg/s
- Z-axis angle < 0.1deg/s
- LS position < 1m




*LIDAR noise simulation*

## Hazard mapping

Our HDA solution starts with a temporal and spatial denoising of the LiDAR signal. A 3D reconstruction is then performed using LiDAR and camera measurements. A classification step, based on machine learning, is then applied to improve slope map. The slope map is finally combined with shadow and roughness maps, using a fuzzy logic technique to select a safe landing site.




**HDA solution is conservative:**

- Very low false positive rate
  (no unsafe site detected as safe in our tests)
- Low detection rate
  (only a few available safe sites are detected, but always one!)

*Hazard maps*